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BENTHIC FAUNAL COLONIZATION OF AN OFFSHORE BORROW PIT IN SOUTHEASTERN FLORIDA

by

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When sediments are dredged from offshore, either for a Corps project or a permitted activity, borrow pits are created. As part of a program to examine the environmental effects of dredging, this study addresses concerns about the changes that may occur in the benthic fauna associated with these dredged borrow sites.

Benthic faunal colonization of a newly created borrow pit off Delray Beach, Florida, was monitored. For comparative purposes, a single sampling of an adjacent 5-year-old borrow pit was conducted concurrently with the final sampling of the new pit. Colonization of the new pit was rapid, with 35 species and 1,081 individuals/square metre collected at the initial sampling, 21 days postdredging. Abundance peaked at a mean density of 1,761 individuals/square metre in the third sampling period (170 days postdredging), and species richness peaked at the fifth sampling period (296 days postdredging) with 57 species. Polychaete annelids and peracarid crustaceans were numerically the most important initial

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colonizers of the new pit, together comprising 89.3 percent of the fauna. Species diversity (H') and equitability were lowest during the first sampling period (4.21 and 0.82, respectively) and, although variable, increased toward the end of the study (5.10 and 0.92, respectively). Relative to the old pit, the disturbed area showed complete recovery based on several aspects of community structure, although differences in species composition were evident.

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PREFACE

This report describes work performed by Florida Atlantic University as part of the Dredging Operations Technical Support (DOTS) Program. The DOTS Program is sponsored by the Headquarters, US Army Corps of Engineers (USACE). DOTS is assigned to the US Army Engineer Waterways Experiment Station (WES), under the purview of the Environmental Laboratory's (EL) Environmental Effects of Dredging Programs (EEDP).

The study was conducted and the report was written by Mr. Philip R. Bowen and Dr. G. Alex Marsh, College of Science, Florida Atlantic University, Boca Raton, Fla.

Technical reviews of this report were provided by Mr. David A. Nelson, Dr. Tom Fredette, Dr. Jurij Homziak, Mr. Jack Pullen, and Mr. John Baker, Environmental Resources Division (ERD), EL. The report was edited by Ms. Jessica S. Ruff of the WES Information Technology Laboratory.

Dr. Robert M. Engler was Manager, EEDP; Mr. Thomas R. Patin was the DOTS Coordinator. Dr. Conrad J. Kirby was Chief, ERD, and Dr. John Harrison was Chief, EL. The work was monitored by Mr. David B. Mathis, Dredging Division, USACE.

Commander and Director of WES was COL Dwayne G. Lee, EN. Technical Director was Dr. Robert W. Whalin.

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PART I: INTRODUCTION

Background

1. When sediments are dredged from offshore, either for a Corps project or a permitted activity, borrow pits are created. As part of a program to examine the environmental effects of dredging, this study addresses concerns about the changes that may occur in the benthic fauna associated with these dredged borrow sites.

2. Dredging for purposes of beach renourishment is a major cause of soft-bottom disturbance along the Florida coast. Between 1969 and 1982, the US Army Corps of Engineers placed more than 50 million cubic yards (38 million cubic metres) of sand onto Florida's beaches (Adams 1980, 1981, 1982). This activity will undoubtedly continue, since it is presently considered the most economical way to combat beach erosion (Walton 1978). A major cause of beach erosion along the open shorelines, in addition to storms and hurricanes, is rising sea level (Walton 1978) which, on the Florida Atlantic and Gulf coasts, averages approximately 3.3 mm per year (Hicks 1973).

3. In recent years, scientists have become increasingly concerned about dredging projects and their possible detrimental effects on the marine environment. Many studies, primarily in estuarine systems, have been conducted to elucidate the environmental impact of dredging on benthic marine fauna. In Florida, the Tampa Bay and Boca Ciega Bay areas have received the most attention. In these areas, the effects of shell dredging, canalization, and land filling have been well documented (Taylor and Saloman 1968; Sykes and Hall 1970; Taylor, Hall, and Saloman 1970; Simon and Doyle 1974a,b; Simon, Doyle, and Conner 1976).

4. The effects of dredging on the offshore environment have not been so intensively studied. Holland, Chambers, and Blackman (1973) studied fish populations before and after a beach restoration project at Lido Key (Pinellas County), Florida. Dredging had apparently caused a temporary increase in fishes along the beach and near the borrow area. Saloman (1974) studied an

offshore borrow area created 3 years previously near Treasure Island (Pinellas County), Florida. He reported a decrease in the diversity and abundance of benthic invertebrates within the pit, relative to adjacent areas. In contrast, Turbeville and Marsh (1982) demonstrated a generally greater abundance of benthic fauna in a borrow area off northern Broward County, Florida, than on a nearby undisturbed bottom.

5. Courtenay et al. (1974) surveyed the fishes and nearshore reef communities off Broward County following a 1971 beach restoration project. No adverse effects were observed on fish populations from Pompano Beach to Lauderdale-by-the-Sea, but substantial physical damage to the reefs was found adjacent to the borrow area off Hallandale. The damage was attributed to careless handling of dredging equipment. In a later study of this area, Courtenay, Hartig, and Loisel (1980) reported the disappearance of the dusky jawfish, *Opisthognathus whitehursti*, and attributed its disappearance to the incursion of beach fill onto the nearshore reef, which reduced the bottom relief and grain size of the substrate. Marsh et al. (1980) quantitatively sampled the benthic communities and nearby reefs adjacent to this area 6 years after dredging and found no apparent long-term deleterious effects from the 1971 restoration project.

6. Saloman, Naughton, and Taylor (1982) studied the short-term effects of beach renourishment on benthic fauna off Panama City Beach (Escambia County), Florida. They reported that the faunal abundance in the borrow area recovered within 3 months postdredging, although faunal assemblages in the disturbed and undisturbed areas were dissimilar. Within 8 to 9 months, recovery was judged to be complete, based on analyses of species richness, abundance, diversity, equitability, faunal similarity, and stability.

7. At Captiva Island (Lee County), Florida, Courtney (1982) reported the disappearance of 61 percent of the invertebrate species (some of numerical importance) and 86 percent of the individuals 3 months after dredging for beach nourishment. However, 9 months after dredging, species richness and diversity were much higher in the borrow area than prior to dredging.

8. Since dredging for purposes of beach restoration will probably increase in the future, and because most impact studies to date have been conducted in bays and estuaries, a need exists for more information concerning the environmental effects of beach restoration, particularly on Florida's southeastern coast. This study was undertaken for the purpose of adding to

the data base concerning the effects of dredging on the offshore soft-bottom environment and the rates at which borrow areas become colonized by benthic fauna.

9. In early 1978 the public beach at Delray Beach (Palm Beach County), Florida, was renourished with approximately 600,000 yd^3 (460,000 m^3) of sand placed onto 1.7 miles (2.7 km) of shoreline. The beach had previously been renourished in June 1973, when approximately 1.6 million cubic yards (1.2 million cubic metres) of sand was placed onto the beaches. Sand for both the 1973 and 1978 renourishment programs was taken from the same general borrow area, affording an ideal opportunity for the present study.

10. The purposes of this study were to: (a) determine rates and patterns of macrobenthic faunal colonization of a newly created borrow area for a period of 1 year, (b) demonstrate temporal changes in community structure within this period, and (c) compare faunal composition and community structure within the disturbed area after 1 year of recovery to that in a nearby area dredged 5 years previously.

Description of Study Area

11. The seafloor off Delray Beach, Florida, slopes at an angle of approximately 6.5 deg toward an outer reef, located about 1,200 m offshore (Figures 1 and 2). Inshore reefs in this area have been sanded over, although south of the study area there are two additional, well-defined reef lines shoreward of the outer reef (Duane and Meisburger 1969). The third, or outer, reef line extends parallel to the coastline approximately 213 m east of the study area. This reef rises from a sandy bottom at a depth of approximately 19.8 m, with its crest lying 13.7 to 15.2 m below the water's surface.

12. The approximate locations of both the new and old borrow pits sampled during this study are shown in Figure 2. The borrow area was dominated by fine sands (2.0 to 3.0 ϕ units) referred to locally as "sugar sand." Sediment composition was approximately 60-percent quartz and 40-percent calcareous fragments (Duane and Meisburger 1969, Williams 1975). The new pit measured approximately 30 m east to west and 130 m north to south. The average water depth within this pit was 24.3 m, while the surrounding bottom had an average depth of 18.6 m.

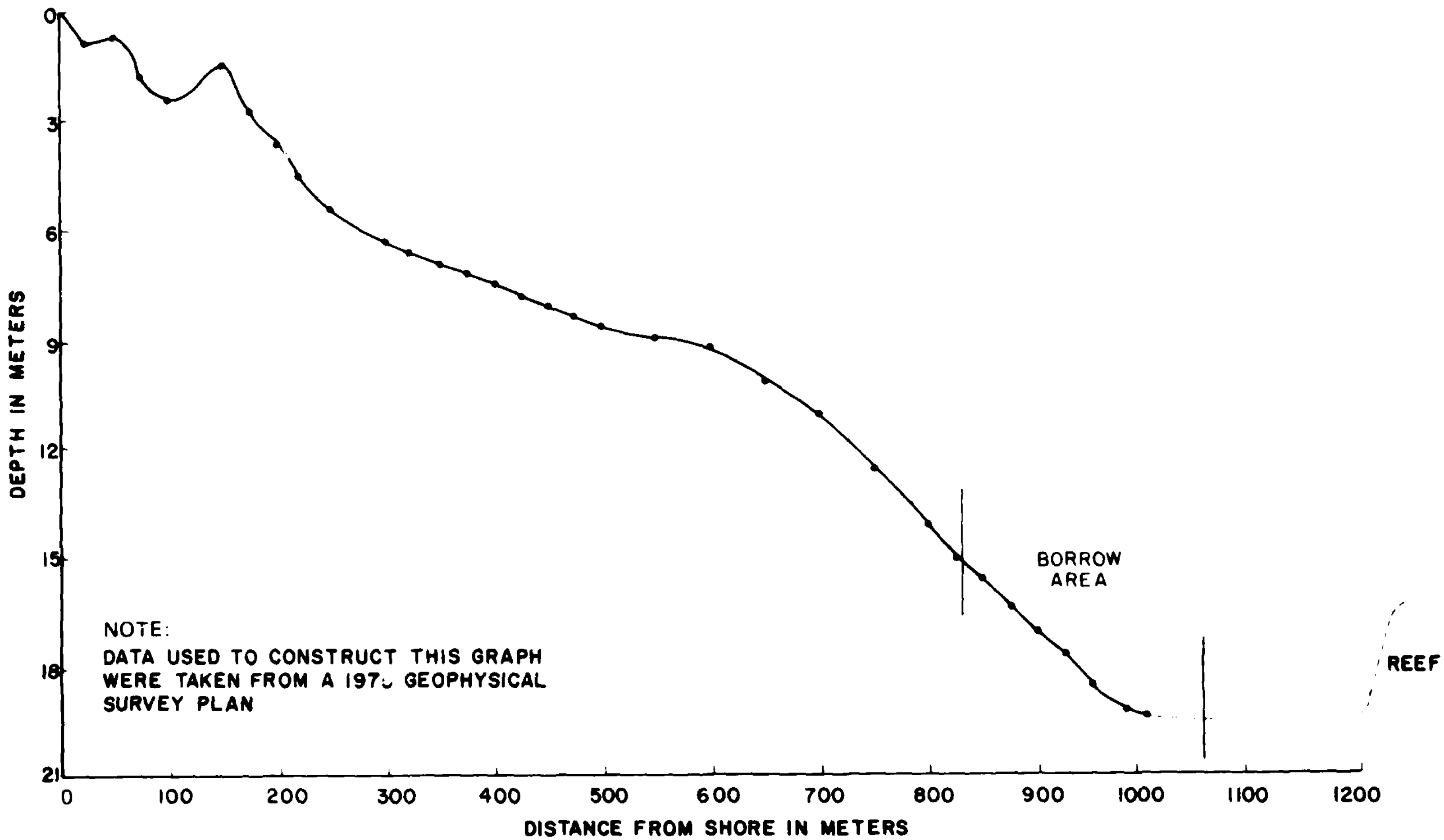

Figure 1. Bottom profile off Delray Beach, Florida

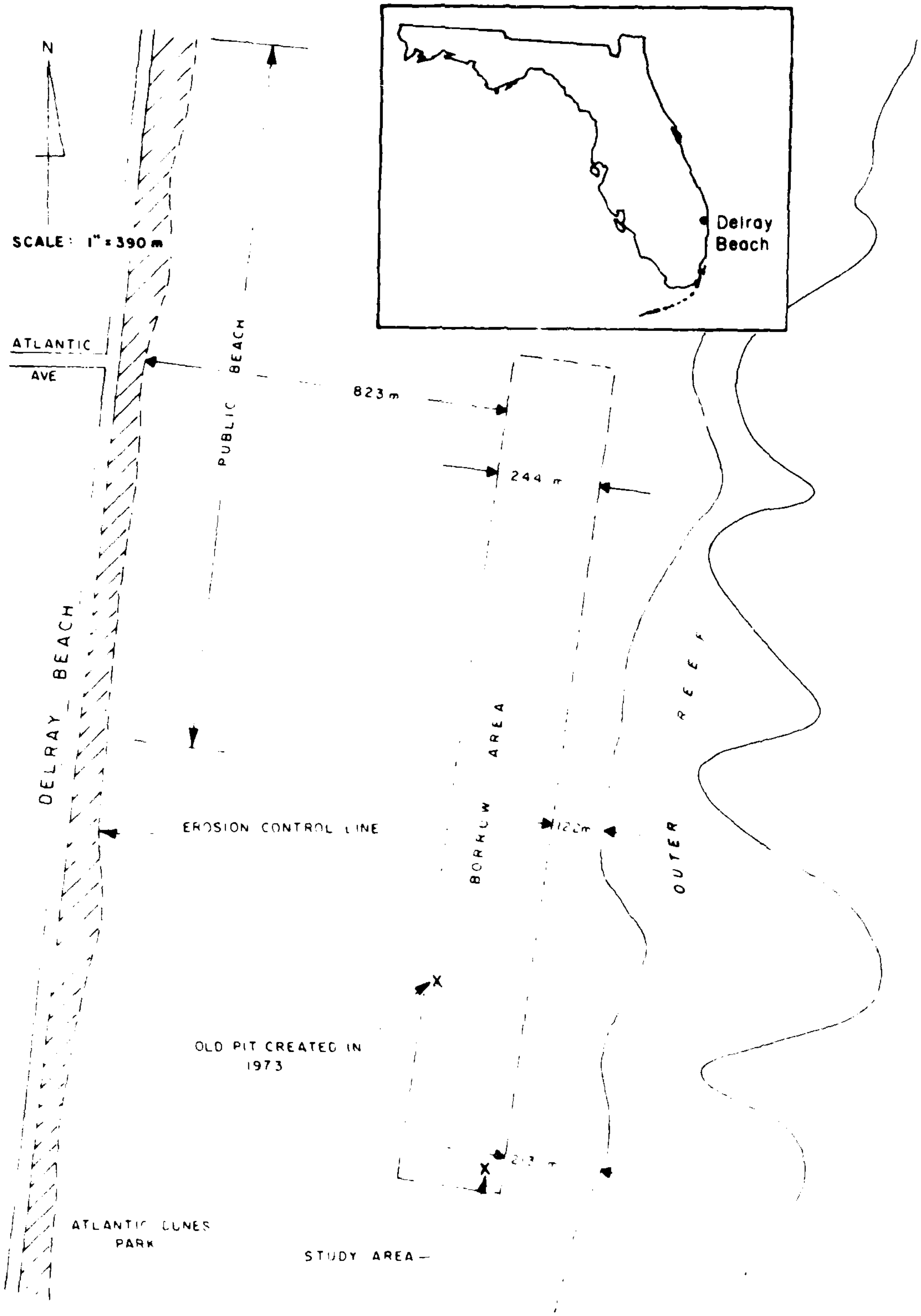

Figure 2. Locations of new and old borrow pits

13. The old pit measured 122 m east to west and 76 m north to south. The average water depth of this pit was 21.6 m, while that of the surrounding bottom was 15.2 m. The old pit is approximately 300 m northwest of the new pit.

14. Both borrow pits appeared to have stable walls sloping at an angle of 40 to 60 deg. Water currents are predominantly southerly through the area although there is considerable variability in both direction and velocity. Variability of currents is influenced by winds, tides, and movements of the Gulf Stream and its spin-off eddies. Annual water temperatures range between 18° and 30° C, while water salinities vary between 33 and 37 ppt, depending primarily on seasonal rainfall patterns and discharge through local inlets.

PART II: METHODS AND MATERIALS

Sampling Procedure

15. Dredging of the new borrow pit was completed on 25 May 1978, and sampling commenced 21 days postdredging. Strong current conditions prevented complete sampling of the new borrow pit prior to this date. Additional samples were taken 98, 170, 246, 296, and 395 days postdredging. The old borrow pit was also sampled at 395 days postdredging for comparison with the sixth sampling period of the new pit.

16. Benthic samples were taken with the aid of SCUBA and a hand-held polyvinyl chloride coring device. The coring device measured 15 cm in length, with an internal diameter of 7.9 cm, giving a sampling area of 0.005 m^2 per core. Samples were collected by inserting the coring device into the sediments to a depth of approximately 11 cm, closing the top with a rubber stopper, then extracting the core while covering the bottom end by hand. Sample cores that did not show full sample recovery were discarded and resampled.

17. During each of the first two sampling periods, 33 benthic core samples were taken randomly within the new pit. Three of these cores were randomly selected for sediment analysis, leaving 30 cores for faunal analysis. During the last four sampling periods, cores for sediment analysis were restricted to the upper 3 cm of sediment, with five replicates employed in addition to the 30 faunal samples. This change was made to detect changes in sediment characteristics near the sediment/water interface where most of the fauna occurred.

18. The contents of each core were emptied into individual 3.8-ℓ plastic storage bags, sealed underwater, and then brought to the surface. A 7-percent solution of $MgCl_2$ was added to each bag to narcotize organisms within the samples. Each bagged sample was wet-sieved separately through a 1-mm screen. All organisms and debris remaining in the sieve were fixed in a 10-percent seawater-formalin solution stained with Rose Bengal. In the laboratory, the organisms were sorted and preserved in 70-percent ethanol. All organisms were later identified to the lowest taxon possible.

19. Adequacy of sample size for number of species was demonstrated by means of cumulative species curves (Figure 3). The curves for the initial and final samplings of the new pit leveled off at approximately 22 to 25 cores,

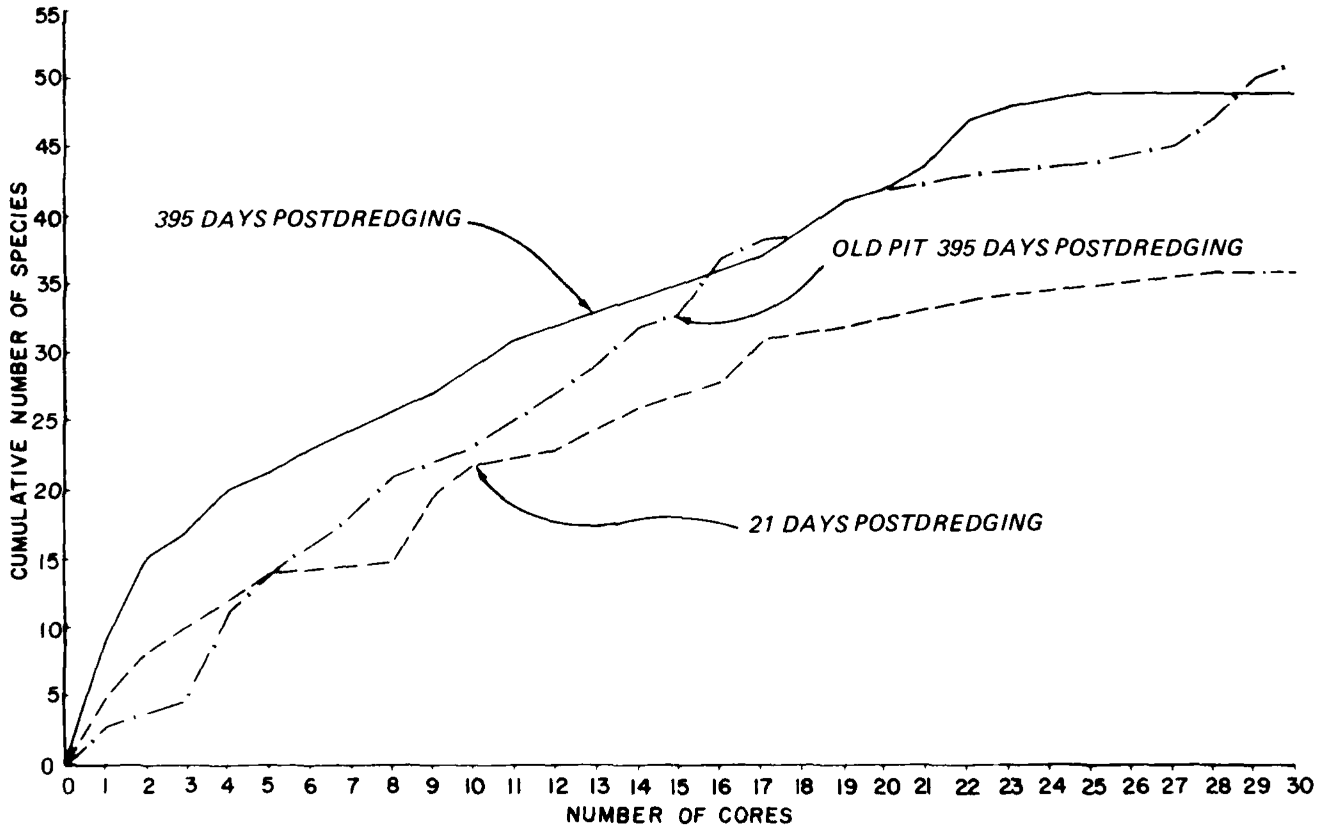

Figure 3. Cumulative species curves for core samples from new pit (two dates) and old pit

indicating that additional replicates would yield few new species. The curve for the old pit still showed occasional rare species at 30 core samples. Voucher specimens of species collected were deposited in the Zoological Museum, Florida Atlantic University, Boca Raton, Fla.

Sediment Analysis

20. An aliquot from each sediment core was dispersed for 24 hr in a 4-percent solution of sodium hexametaphosphate (Calgon) and then washed through a 0.063-mm sieve to separate the silts and clays from the sand. After oven-drying at 90° C for 24 hr, the sand was fractionated with a standard sieve series according to the Wentworth scale. Each fraction was weighed to the nearest 0.01 g.

21. Organic content was determined by oven-drying an additional sediment aliquot and then measuring the percent weight loss after incineration at 500° C for 1 hour.

22. Grain size-related parameters, including mean grain size, sorting, skewness, and kurtosis, were calculated from size frequency data using the SEDANA computer program of Bloom, Santos, and Field (1977). Equations used in the program are those of Folk and Ward (1957). SEDANA offers three choices of calculated data: central concern, peripheral concern, and extreme peripheral concern. To gain maximum information from each sediment parameter, extreme peripheral concern, mean grain size, skewness, kurtosis, and sorting values were used.

23. Differences in grain sizes between sediment samples at each sampling period and among sampling periods were estimated using a single-classification, Model I analysis of variance (ANOVA) (Sokal and Rohlf 1969).

Faunal Analysis

24. Benthic fauna collected during each sampling period were analyzed for significant differences in numbers of individuals and numbers of species. Frequency data for each sampling period, initially nonnormal, were normalized using the square root transformation. A single-classification Model I ANOVA was performed according to the method of Sokal and Rohlf (1969).

25. Species diversity was calculated using the Shannon-Wiener index (H'):

$$H' = -\sum_{i=1}^{S} P_i \log_2 P_i \tag{1}$$

where

S = total number of species

P_i = probability that one individual belongs to species i; n_i/N

n_i = number of individuals of the i^{th} species

N = total number of individuals in the sample

The equitability component of diversity (Pielou 1966) was calculated as follows:

$$e = \frac{H'}{\log_2 S} \tag{2}$$

26. Faunal similarity among samples within the new pit and, for the last sampling period, between the new and old pits was tested using Sorensen's coefficient (Sorensen 1948), also known as Czekanowski's coefficient (CCs) (Wolda 1981)

$$CC_s = \frac{2W}{A + B} \tag{3}$$

where

A = sum of all species in one community

B = similar sum for the second community

W = sum of the species common to both communities being compared

Although this index is widely used in the literature, the results are inadequate in many circumstances since they do not take into account the relative abundances of the various taxa. This coefficient is most useful when the major interest can be satisfied by consideration of the presence or absence of species only.

27. To remedy this, the Proportional Similarity (PS) Index was used, in addition to Sorenson's Index. It takes into account species abundances in each of the two or more communities being compared (Wolda 1981). This index is

$$PS = \sum X_i \text{ or } Y_i \text{ (whichever is lower)} \qquad (4)$$

where

X_i = percent composition of species i in the first community

y_i = percent composition of that species in the second community

PART III: RESULTS

Sediments

28. Grain size distribution and organic content for each sampling period are shown in Table 1. The dominant grain size within the new pit was fine sand (2.0 to 3.0 ϕ), with a mean grain size of 2.6 ϕ. Sediment organic content was greatest during the first two sampling periods (2.17 and 2.36 percent) and ranged between 1.20 and 1.79 percent during succeeding sampling periods.

29. Seasonal differences in mean grain size, sorting coefficient, skewness, and kurtosis are shown in Table 2. The sorting coefficient describes the average spread in grain size about the central tendency of the cumulative percent grain size curve. It indicates the degree of sorting of particles in the sample. Sediments of this study ranged between moderately well sorted and sorted (Bloom, Santos, and Field 1977). An increase of fines (silts and clays) in the sediments of the second sampling period (Table 1) caused a reduction in mean grain size (2.91 ϕ) and caused the sorting coefficient to increase into the moderately sorted range (0.97). Reasons for the unusually high percentage of fines (14.4 percent) in the sediments of the second sampling period are unclear. Perhaps one or more of the sediment replicate samples was collected from a depression on the bottom that had been filled with fines that settled during and after the dredging operation.

30. Skewness indicates the displacement of the median from the mean grain size and is independent of the sorting coefficient. An excess of fine material in the sample would cause the curve to skew toward the right (positive). Sediments of the new pit were "fine skewed" (0.18 to 0.33) immediately following dredging and through the third sampling period. The fourth and sixth sampling periods showed that sediments were nearly symmetrical (skewness of zero).

31. Kurtosis is a measure of the ratio of sorting in the extremes of the distribution to sorting in the central portion of the cumulative percent grain size curve. If the central portion of the distribution is better sorted than the tails, the curve is excessively peaked, or leptokurtic; if the tails are better sorted than the central portion, the curve is flattened, or platykurtic; if the tails and the central portion are similarly sorted, the curve

Table 1

Percent Particle Size Distribution and Percent Organic Content of Sediments for Each Sampling Period

No. Days Postdredging	-2 ϕ	1 ϕ (Gran-ules)	0 ϕ (Very Coarse Sand)	+1 ϕ (Coarse Sand)	+2 ϕ (Medium Sand)	+3 ϕ (Fine Sand)	+4 ϕ (Very Fine Sand)	+5 ϕ (Silts and Clay)	Percent Organic Content
21	0.01	0.09	0.82	1.45	3.40	76.38	13.65	4.20	2.17
98	--	0.81	1.83	1.81	3.33	61.15	16.63	14.44	2.36
170	--	--	0.44	0.84	2.79	66.87	22.69	6.37	1.70
246	0.02	0.29	0.73	1.21	9.50	66.13	21.32	0.80	1.28
296	0.19	0.21	0.42	0.97	4.72	60.87	31.21	1.41	1.71
395	--	0.05	2.58	1.36	4.29	57.01	33.29	1.42	1.79
395 (Old Pit) (Reference)	0.77	1.70	2.68	5.40	11.84	68.31	8.27	1.03	1.20

Table 2

Statistical Sediment Characteristics

Statistic	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	395 Days (Old Pit)
Mean grain size (ϕ units)	2.62	2.91	2.81	2.64	2.80	2.81	2.25
Sorting coefficient	0.58	0.97	0.68	0.69	0.68	0.76	0.90
Skewness	0.18	0.25	0.33	0.07	0.12	0.02	-0.34
Kurtosis	1.36	1.32	1.04	1.36	0.96	1.09	2.00

would be moderately peaked, or mesokurtic. Sediments of the present study were leptokurtic (1.04-1.36) during the first, second, and fourth sampling periods and mesokurtic during the third, fifth, and sixth sampling periods.

32. Single classification ANOVA showed sediment grain sizes within the new pit to be generally heterogeneous ($p < 0.025$). Heterogeneity was greatest at the first sampling period as indicated by the wide 95-percent confidence interval (Figure 4). Separation of the variance components (coefficient of intraclass correlation) showed the heterogeneity to be primarily within samples of each sampling period rather than between sampling periods, indicating that there were considerable spatial differences of sediments within the pit.

Fauna

Colonization patterns

33. Numbers of species and individuals collected in the new borrow pit during each sampling period are shown in Figure 5. If one assumes that no species were present immediately after dredging, the curves show a rapid increase in species and individuals during the initial weeks of the study. The first sampling period, occurring only 21 days after dredging, yielded 35 species at an average extrapolated faunal density of 1,081 individuals/m^2 (Table 3). In subsequent sampling periods, species richness showed a general but irregular increase, peaking at 57 species in the fifth sampling period. Numbers of individuals collected increased through the third sampling period,

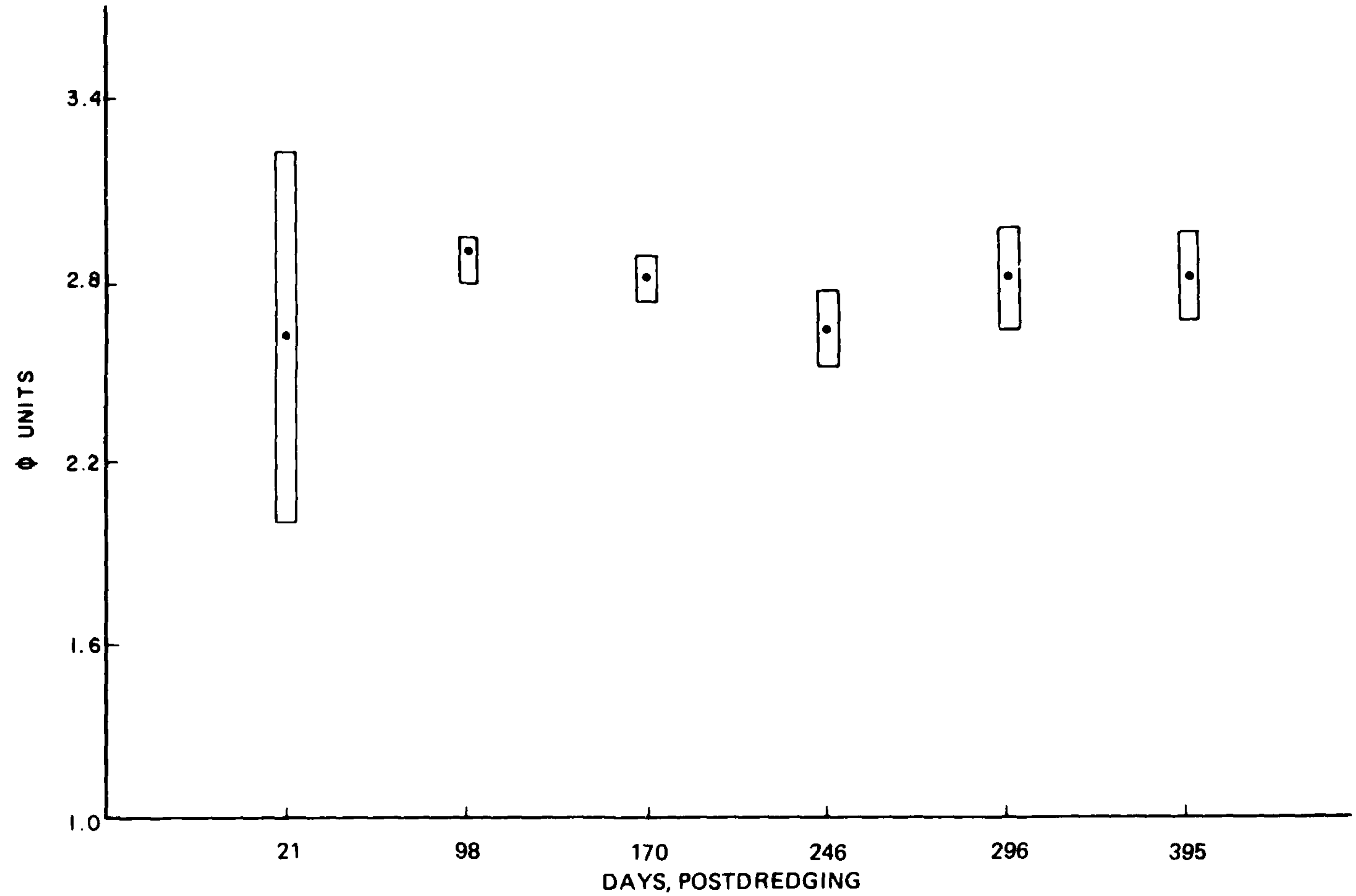

Figure 4. Sediment mean grain size (ϕ units). Points are mean values; bars are 95-percent confidence limits

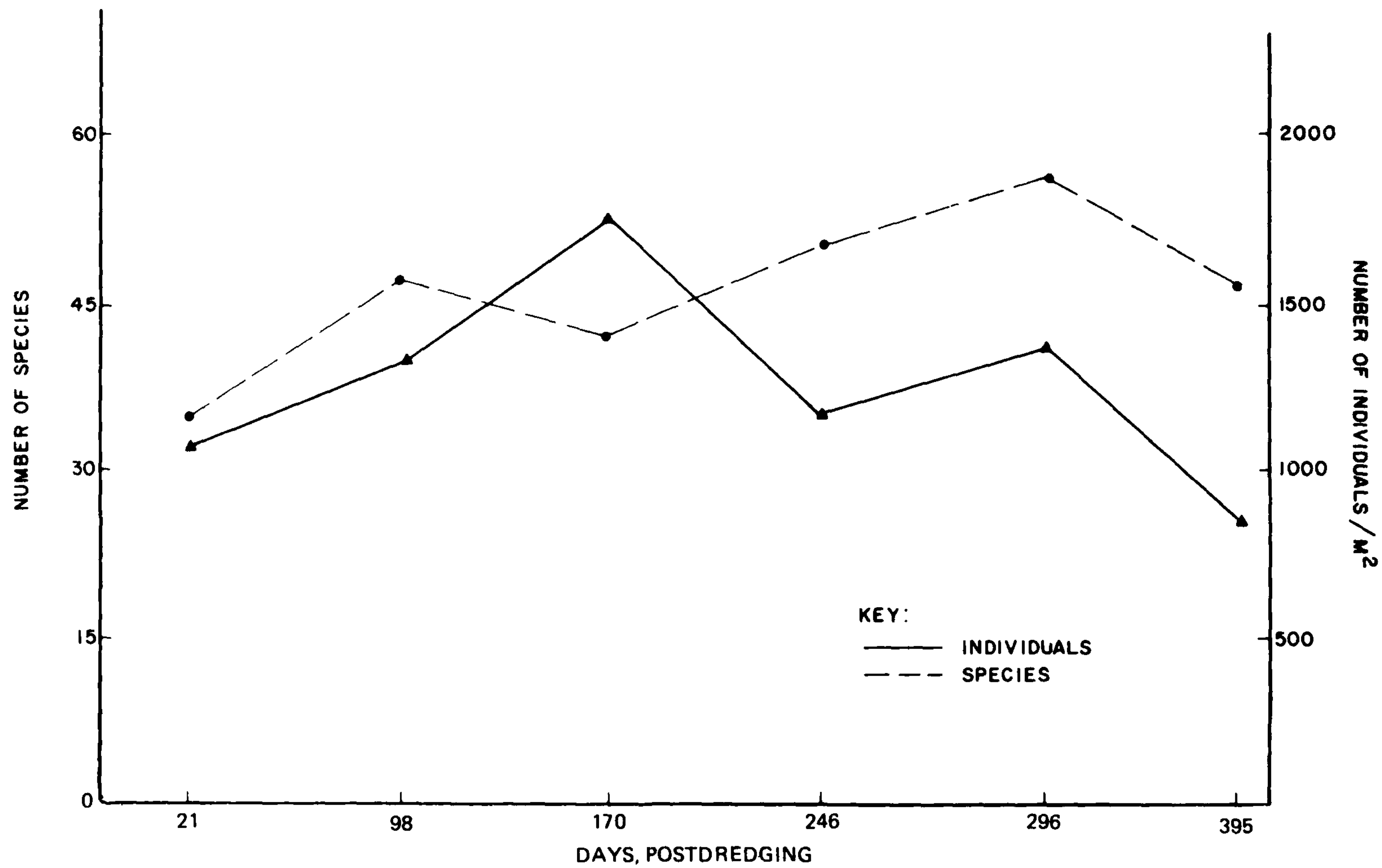

Figure 5. Number of species and extrapolated faunal densities collected at each sampling period

Table 3

Total Number of Species, Individuals, Extrapolated Faunal Densities, and Diversity and Equitability Values for Each Sampling Period

Sampling Period*	Number of Species	Density (Individuals/m^2)	Diversity H'	Equitability e
		New Pit		
1 - 21 days	35	1,081	4.21	2.73
2 - 98 days	48	1,326	4.77	2.84
3 - 170 days	43	1,761	4.34	2.66
4 - 246 days	51	1,170	4.70	2.76
5 - 296 days	57	1,374	5.09	2.90
6 - 395 days	47	870	5.10	3.05
		Old Pit		
6 - 395 days	50	694	5.11	3.01

* Number of days postdredging.

reaching a maximum mean density of 1,761 individuals/m^2. Thereafter, densities decreased irregularly, reaching a low mean value of 870 individuals/m^2 in the last sampling period, a decrease of 19.5 percent from the initial period.

34. A total of 1,115 individuals comprising 138 animal species were collected from the new pit during the study (Appendixes A and B). Two macroalgal species were also collected and included in the appendixes but were not used in quantitative analyses. Ten species made up 50 percent of all individuals collected within the new pit (Appendix A). These included six polychaete species (*Aricidea philbinae*, *Lumbrineris testudinum*, *Haploscoloplos foliosus*, *Chone* sp. 1, *Prionospio fallax*, and *Paraprionospio pinnata*), two amphipods (*Phtisica marina* and *Ampelisca abdita*), one bryozoan (*Cupuladria* sp.), and one bivalve (*Parvilucina multidentata*). Some variation in species composition occurred among dominants during the study period (Appendix B). Only seven species were collected during all six sampling periods: *Aricidea philbinae*, *Lumbrineris testudinum*, *Chone* sp. 1, *Prionospio fallax*, *Parvilucina multidentata*, *Aricidae* sp. 1, and *Armandia maculata*.

35. Sorensen's similarity coefficient was used to compare faunal similarity among sampling periods within the new pit (Figure 6). Consecutive

sampling periods were more similar to each other than to other sampling periods in every case except the fifth and sixth sampling periods. The abrupt decrease in similarity between the fifth and sixth sampling periods was due primarily to the disappearance of several formerly abundant molluscan species. Three bivalve dominants in the fifth sampling period, *Codakia* sp., *Tellina versicolor*, and bivalve sp. 1, were absent altogether in the sixth sampling period, along with six species of gastropod molluscs (Appendix B). When the proportional similarity index, weighted for abundance (Figure 7), was used, the same pattern existed between consecutive sampling periods except for the magnitude of difference between the fifth and sixth sampling periods.

36. A considerable difference was evident between the two index values for sampling periods 4 months apart. When sampling period I was compared to sampling period III, the index values 0.38 (Sorensen's Index) and 0.21 (proportional similarity index) were obtained. This pattern was consistent throughout the study (Figures 6 and 7).

37. Polychaete annelids accounted for 54.2 percent of the species (Appendix B) and 67.3 percent of the individuals (Figure 8) collected during the first sampling period. Polychaetes not only established themselves rapidly, but continued to account for a major portion of the species (43.7 to 56.9 percent) and individuals (44.2 to 71.9 percent) collected throughout the study.

38. Crustaceans, primarily peracarids, also rapidly colonized the borrow pit. In the first sampling period, seven crustacean species were present, including two amphipod, one cumacean, one tanaidacean, one copepod, and two decapod species (Appendix B). These species comprised 24.5 percent of the total fauna. Within 2 months (at sampling period II), the number of crustacean species had increased to 13 but comprised only 12.8 percent of the fauna (Figure 8). Each of the remaining collections yielded five to eight species of crustaceans comprising 7.7 to 24.5 percent of the fauna.

39. Molluscs were relatively slow to colonize the disturbed area. Only four to six molluscan species were present at each of the first four sampling periods (Appendix B). Between the fourth and fifth sampling periods a sharp increase in species numbers occurred, from 4 to 16. The species present at the fifth sampling period included 10 bivalve and 6 gastropod species, accounting for 18.5 percent of the individuals collected (Figure 8). Gastropods were minor components of the community and were not collected during the second or third sampling periods.

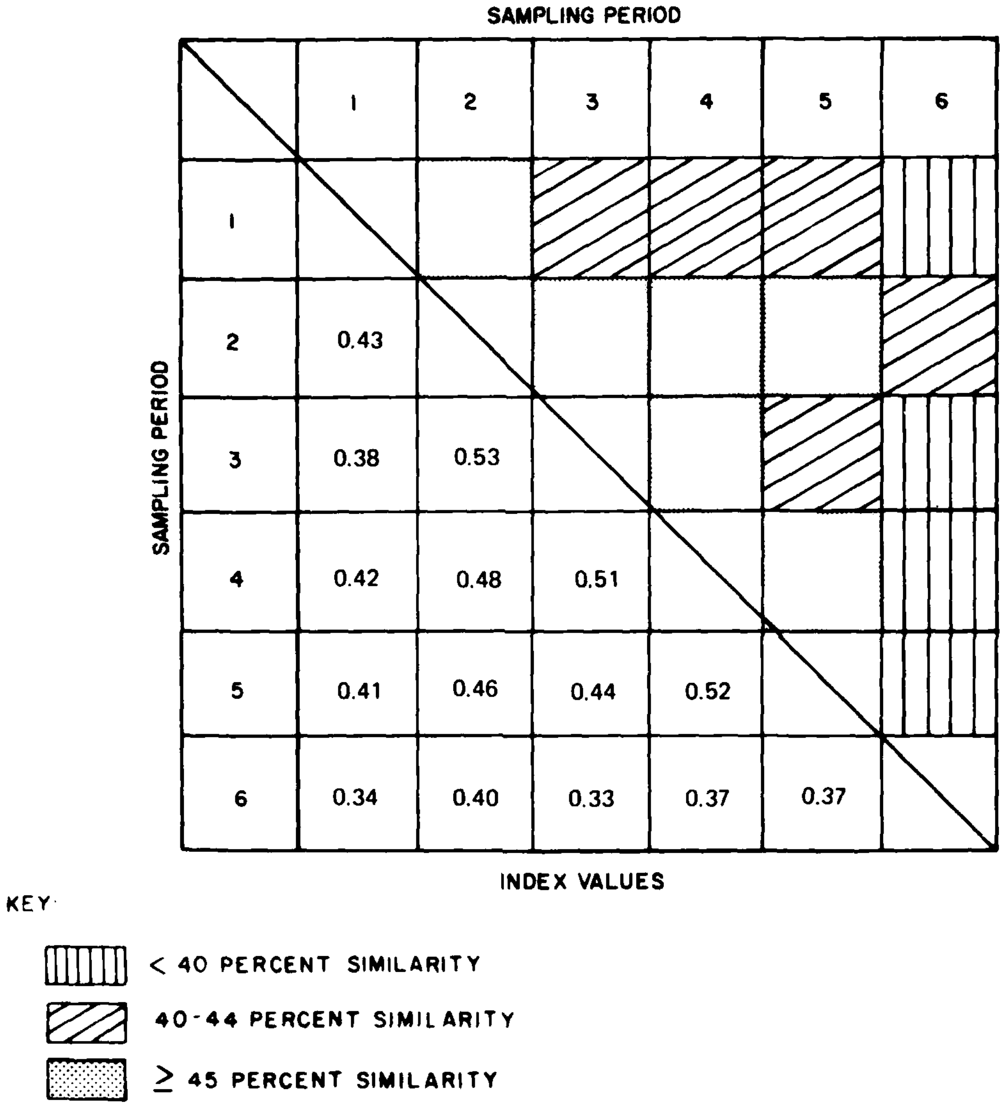

Figure 6. Trellis diagram of Sorensen's similarity index showing species similarity between sampling periods in the new pit

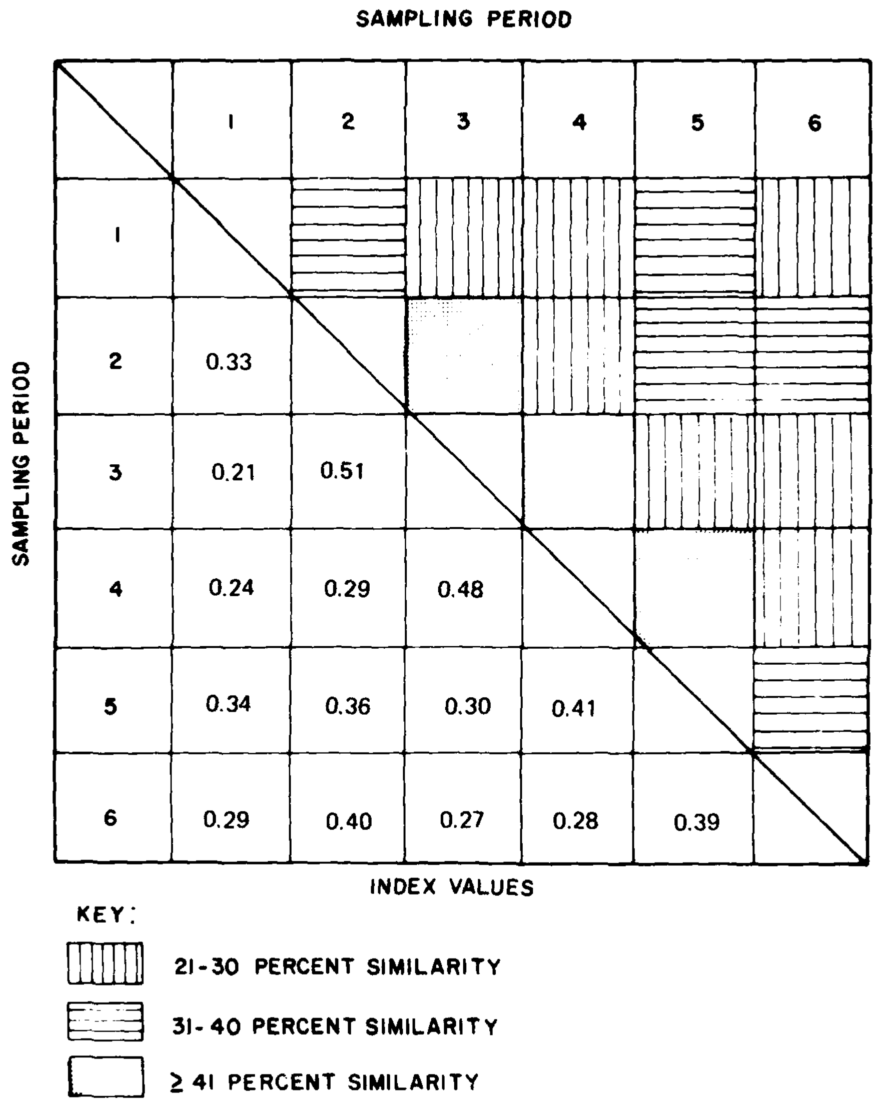

Figure 7. Trellis diagram of the proportional similarity index showing abundance similarity between sampling periods in the new pit

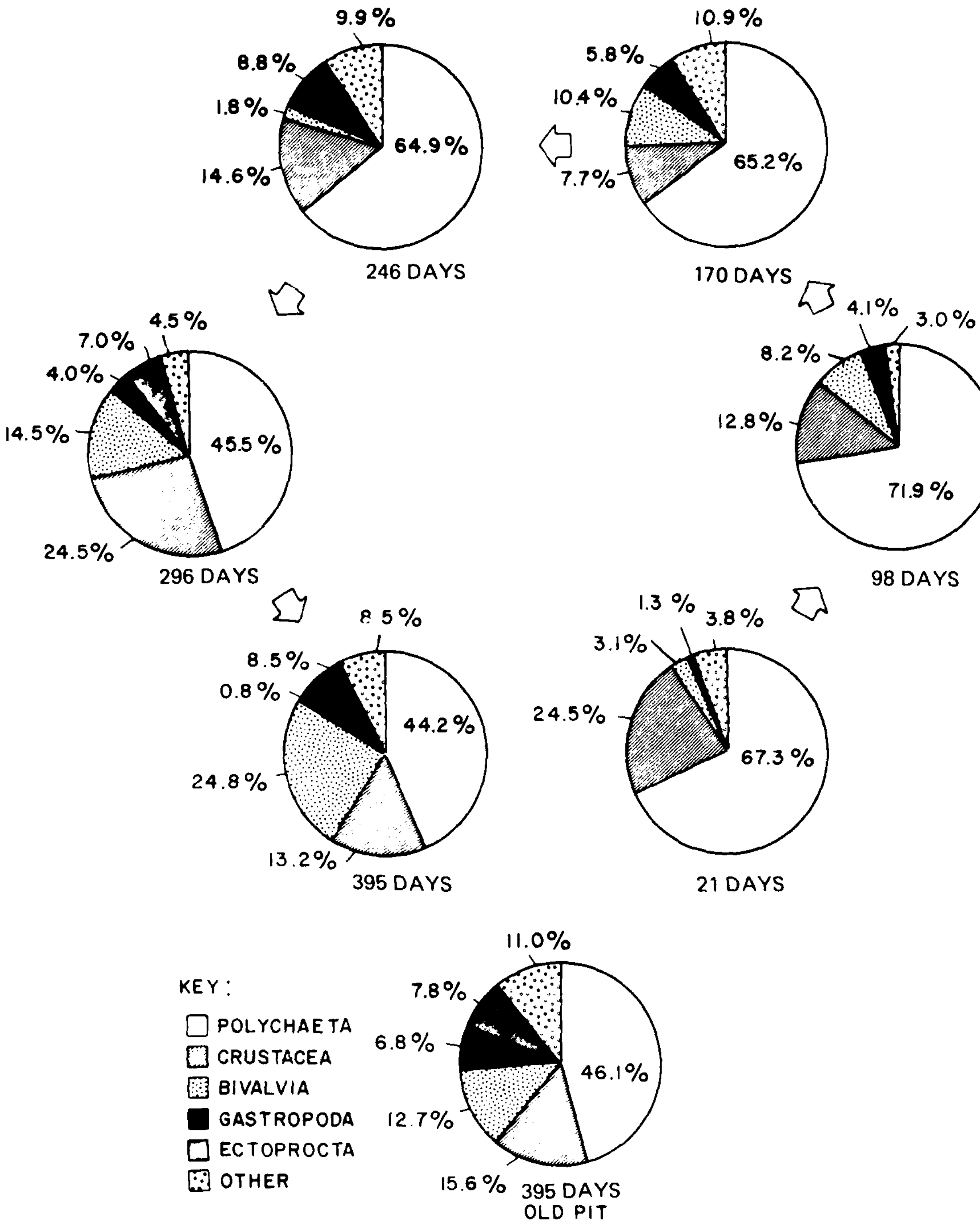

Figure 8. Percent composition of major taxonomic groups in the new and old borrow pits by sampling period (number of days postdredging)

Community structure

40. Several components of community structure were analyzed to evaluate recovery of the disturbed habitat, both structurally (species diversity, equitability, and dominance) and functionally (polychaete trophic and motility types). Comparisons of data from the new and old pits and with the results from other studies are addressed later in the report.

41. Species diversity. Species diversity (H') was lowest during the first sampling period (4.21). Although variable, both H' and equitability (e) showed a general increase toward the end of the study (Table 3). While the sixth sampling period showed the lowest overall faunal density documented during the study (870 individuals/m^2), it produced the highest H' (5.10) and e (3.05) values (Table 3).

42. Species dominance was greatest at the first sampling period, when nine species comprised 74.8 percent of the individuals. Although variable throughout the study, dominance decreased toward the end of the study when 19 species were required to account for 75 percent of the individuals (Table 4). Only one species, *Aricidea philbinae*, occurred consistently as a dominant in each of the six sampling periods (Table 4).

43. Polychaete functional groups. Analysis of functional group distribution through time is important in assessing functional recovery of fauna within a disturbed area (Heatwole and Levins 1972). Polychaete feeding and motility types were analyzed in this regard since these organisms were the dominant taxa throughout the study and because information is available in the literature regarding their use for this purpose.

44. Three trophic types were distinguished based on trophic and motility information provided by Fauchald and Jumars (1979): (a) infaunal feeders, which ingest living and nonliving material together with sediments below the sediment surface, (b) surface feeders, including both suspension and surface-deposit feeders, which ingest detritus and small living food together with a small amount of sediment, and (c) omnivores, which feed primarily as macrophagous carnivores or herbivores, but also as facultative detritivores (e.g., they handle food particles individually, or at most, a few at a time).

45. Motility types are a component of foraging strategy (Fauchald and Jumars 1979). The structure of the feeding apparatus may require that the animal remain stationary while feeding, or the use of the feeding apparatus may be independent of, or require, locomotion for proper function. Fauchald

Table 4

Numbers of Individuals/Square Metre (Inds/m^2) and Percent Composition for Species Comprising 75 Percent of the Individuals Collected During Each Sampling Period

Species	21 Days*		98 Days		170 Days		246 Days		296 Days		395 Days	
	Inds/m^2	% of Sample	Inds/m^2	% of Sample	Inds/m^2	% of Sample	Inds/m^2	% of Sample	Inds/m^2	% of Sample	Inds/m^2	% of Sample
Phtisica marina	178											
Terebellidae sp.	137	12.7							21	1.5	27	3.2
Aricidea sp. 1	123	11.4	28	2.1	41	2.3						
Aricidea philbinae	103	9.5	95	7.2	306	17.4	20	1.7	35	2.5	61	7.1
Branchiomma sp.	82	7.5					55	4.7				
Chone sp. 1	55	5.1	20	1.5			102	8.7	143	10.3	14	1.6
Prionospio fallax	48	4.4	102	7.7			14	1.2	103	7.4	54	1.6
Armandia maculata	41	3.8	82	6.2			14	1.2	35	2.5	34	4.0
Agridae sp. 1	41	3.8										
Haploscoloplos foliosus			198	14.9	176	10.0	27	2.3				
Paraprionospio pinnata			102	7.7	150	8.5						
Lumbrinereis testudinum			74	5.6	252	14.3	164	14.0			14	1.6
Parvilucina multidentata			58	5.1	69	3.9		8.7	40	2.9	81	9.5
Cupuladria sp.			54	4.1	102	5.8	102		96	6.9	74	8.7
Glycera tesselata			41	3.1								
Prionospio dayi			28	2.1					47	3.4	21	2.4
Orbiniidae sp.			28	2.1								
Aloneus floridanus			28	2.1								
Veneridae sp. 1			28	2.1								
Capitellidae sp.			20	1.5					21	1.5		
Ampelisca abdita					69	3.9	123	10.5	40	2.9		
Codakia orbicularis					69	3.5						
Cirrophorus furcatus					48	2.7	20	1.7			21	2.4
Oligochaete sp. 2					41	2.3						
Nemertea sp. 4					33	1.9						
Ophelina sp.							109	9.3	47	3.4	27	3.2
Fabricia sabella							34	2.9				

(Continued)

* Number of days postdredging.

Table 4 (Concluded)

Species	21 Days*		98 Days		170 Days		246 Days		296 Days		395 Days	
	Inds/m^2	% of Sample	Inds/m^2	% of Sample	Inds/m^2	% of Sample	Inds/m^2	% of Sample	Inds/m^2	% of Sample	Inds/m^2	% of Sample
Ophiuroidae sp. 1							34	2.9				
Sthenelais boa							27	2.3				
Rhepoxynius episforma							27	2.3	75	5.4		
Megalomma pettiboneae							20	1.7				
Bivalve sp. 1									54	3.9		
Hippolytidae sp.									47	3.4	27	3.2
Corbulidae sp.									35	2.5		
Cyclapsis varians									28	2.0	14	1.5
Tellina versicolor									28	2.0		
Prionospio cirribranchia									21	1.5		
Branchiostoma caribaeum									21	1.5		
Lucina nassula											41	4.3
Telidora sp.											34	4.0
Spio sp.											27	3.2
Processa bermudensis											27	3.2
Nemertea sp. 12											21	2.4

and Jumars (1979) defined three motility types based on these considerations: (a) sessile organisms include those that do not move sufficiently during their lifespan to feed in an area appreciably different from the one in which they settled as larvae, (b) discretely motile organisms include those capable of moving between feedings, but are sessile during food intake, and (c) motile organisms are those that generally do not move independently of the use of the feeding apparatus or which require movement for proper functioning of the feeding apparatus.

46. Trophic group distribution, based on percent of individuals, changed considerably during the course of the study (Figure 9). Surface-feeding polychaetes were dominant during most of the study. This group comprised 85 percent of the polychaetes at the first sampling period (Figure 9). Surface feeders were least prevalent during the fourth sampling period (43 percent). Infaunal feeders comprised 12 percent of the polychaetes collected at the first sampling period. Their relative abundance tripled to 36 percent by the second sampling period and subsequently stabilized at about 20 percent of the sample. Omnivorous feeders comprised only 3 percent of the polychaete sample at the first sampling period. Subsequently, omnivores showed an increase in abundance through the fourth sampling period when they comprised 36 percent of the sample, their peak abundance.

47. Polychaete motility types also showed a high degree of variation during the study (Figure 10). Motile polychaetes were dominant through most of the study, composing between 37 and 79 percent of the polychaete species (Figure 10). This group was least prevalent during the fifth sampling period when there was approximate parity among all three motility types (Figure 10): motile, discretely motile, and sessile.

48. The importance of a few species was evident when functional groups were analyzed. Individuals of four species, *Aricidea philbinae, Aricidea* sp. 1, *Terebellidae* sp., and *Branchiomma* sp., accounted for 75 percent of the surface-feeding polychaetes at the first sampling period. Two of these, *A. philbinae* and *Aricidea* sp. 1, were also responsible for 86 percent of the motile polychaetes, while two others, *Terebellidae* sp. and *Branchiomma* sp., accounted for 62 percent of the sessile polychaetes collected at the first sampling period.

49. Species dominance within functional groups peaked during the third sampling period. Three species, *A. philbinae, Lumbrineris testudinum*, and

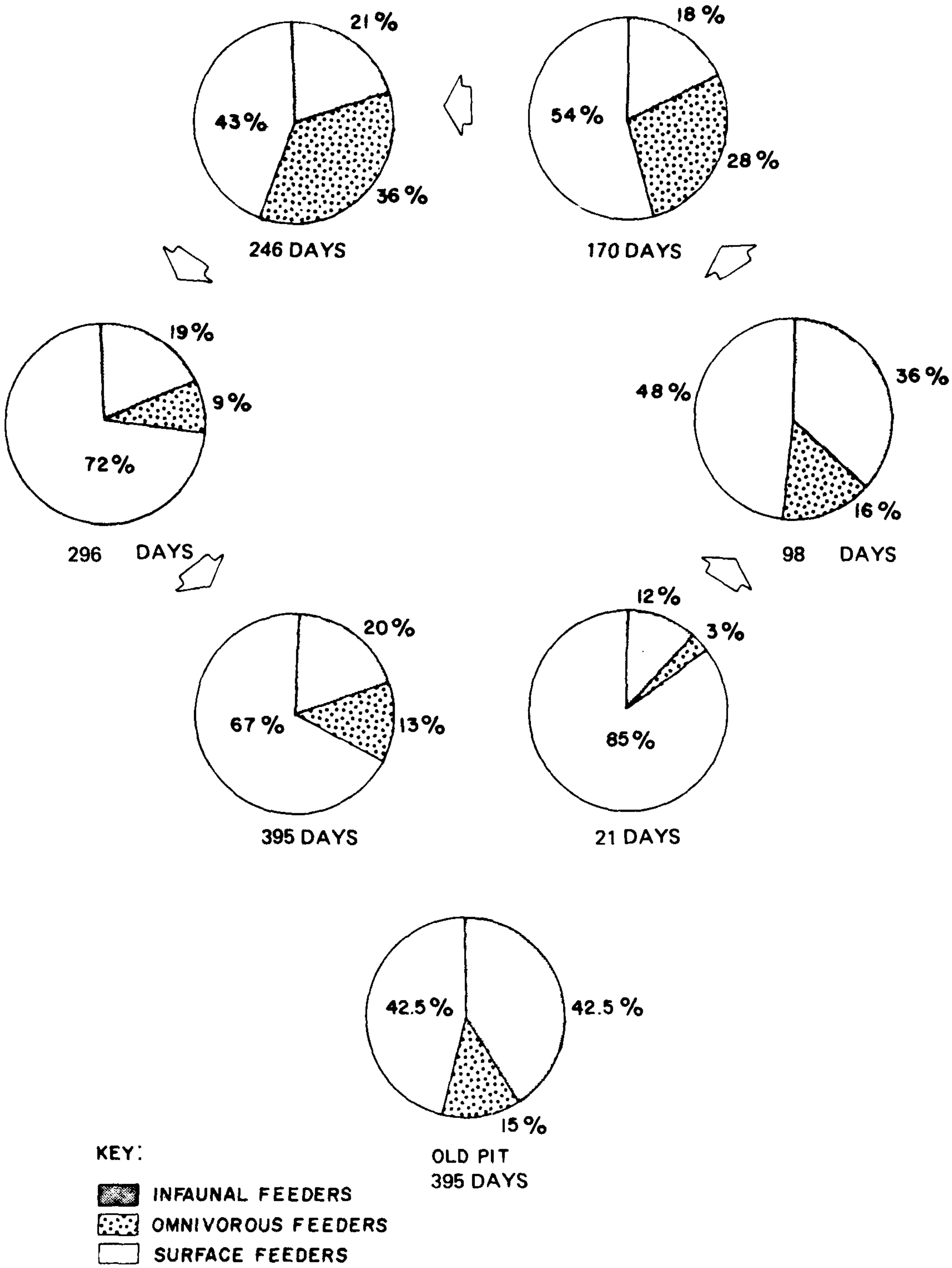

Figure 9. Percent composition of polychaete trophic groups for the new and old borrow pits at Delray Beach (number of days postdredging)

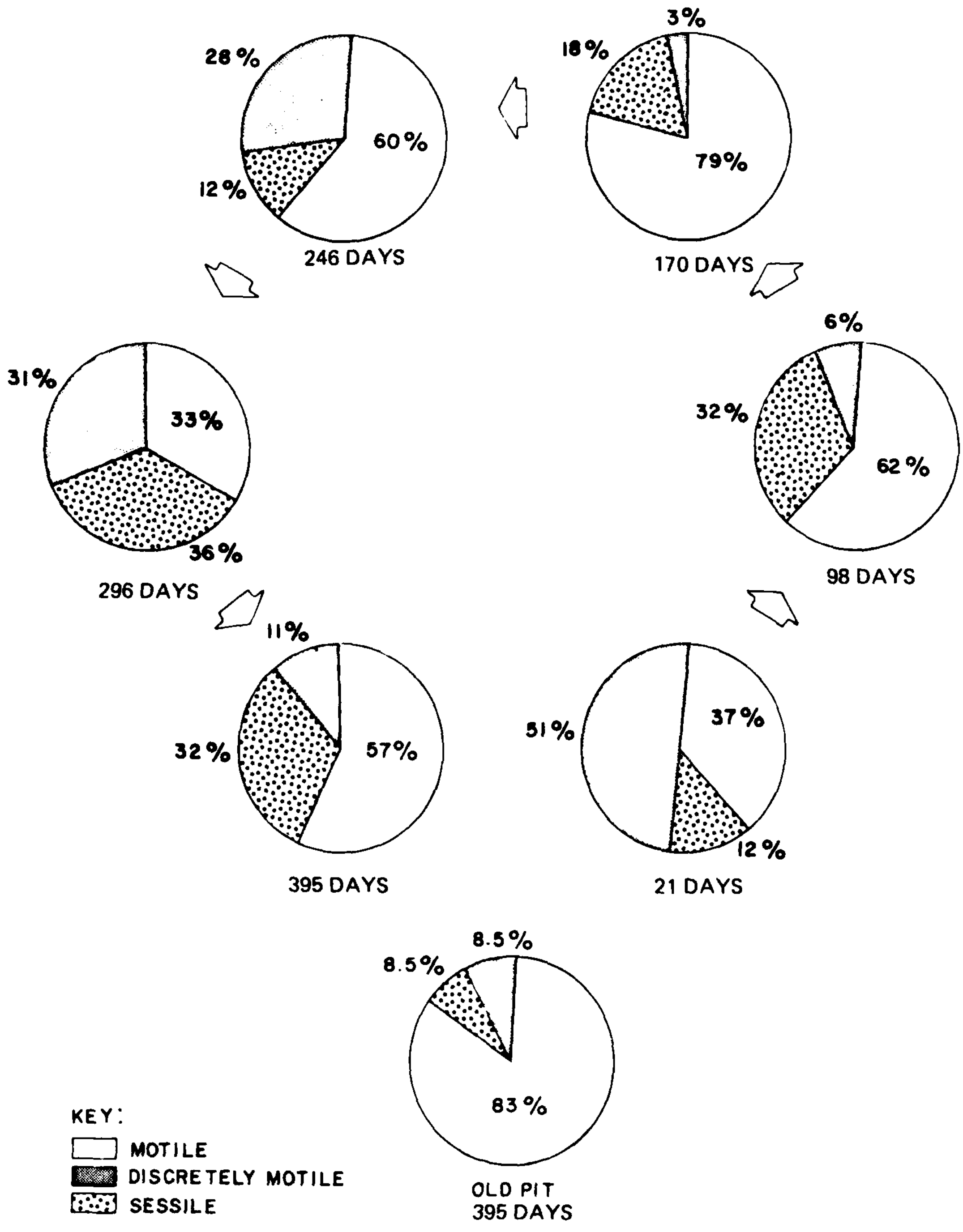

Figure 10. Percent composition of polychaete motility groups for the new and old borrow pits at Delray Beach (number of days postdredging)

Haploscoloplos foliosus, accounted for 79 percent of the motile polychaetes in the third sampling period. One species, *Paraprionospio pinnata*, was responsible for 71 percent of the discretely motile polychaetes. Similar dominance of trophic types occurred, with two species, *A. philbinae* and *P. pinnata*, accounting for 72 percent of the surface feeders and a single species, *H. foliosus*, accounting for 77 percent of the omnivorous types. Functional group dominance declined following the third sampling period.

Old Pit

50. Mean sediment grain size was larger in the old pit (2.25 ϕ) than that found in the final sampling of the new pit (2.81 ϕ) (Table 2). In addition, sediments of the old pit were negatively skewed and very leptokurtic (Table 2) compared to sediments of the new pit, which were positively skewed and less leptokurtic (Table 2). Statistical analysis (ANOVA) showed sediments from the new and old pits to be significantly different ($p < 0.001$).

51. Samples collected from the old pit yielded 50 species (Appendixes C and D) and an average density of 694 individuals/m^2 compared to 47 species and 870 individuals/m^2 in the new pit (Table 3). The numerically dominant species in the old pit was a polychaete annelid, *A. philbinae*, which accounted for 13.7 percent of the sample. This species accounted for 7.1 percent of the fauna in the sixth sampling period in the new pit and was one of the seven species collected at all six sampling periods in the new pit. The next three most abundant species included an ectoproct (*Cupuladria* sp.), an amphipod crustacean (*Rhepoxynius episforma*), and a cephalochordate (*Branchiostoma caribaem*). These species made up 7.8, 5.9, and 4.9 percent of the sample, respectively. Each of these species also occurred in the new pit, although only *Cupuladria* sp. was collected in the last sampling period.

52. Samples from the new pit were very similar, at higher taxonomic levels, to those collected the same day from the old pit, although only 31 percent of the species were common to both areas (Figure 8). The major differences were in the frequency of gastropods and bivalves, which were more abundant in the old pit. Gastropods comprised 6.8 percent of the individuals within the old pit and 0.8 percent of the individuals in the new pit (Figure 8) at the last sampling period.

53. Nine species comprised 50 percent of the sample in both the new and old pits (Table 5). Five species from this group were common to both pits. When the total faunal assemblage from both pits was compared using Sorensen's similarity index, the index value was $CC_s = 0.31$ (Table 6). When the index was weighted for species abundance, the value was slightly higher, PS = 0.35 (Table 6).

54. Comparisons of the old and new pits at the last sampling period using ANOVA showed no significant difference in total abundance or number of species ($p < 0.05$).

55. Other aspects of community structure were very similar in the old and new pits. Species diversity (H') was high (5.11 and 5.10, respectively), as was the equitability component of diversity (3.01 and 3.05, respectively). Dominance was lower in the old pit where 25 species were required to account for 75.5 percent of the sample (Appendix C), while 19 species were required to account for 74.8 percent of the sample (Table 6) in the new pit.

56. Functionally, the old pit differed from the new pit (Figures 9 and 10) except with regard to omnivorous feeders, which composed 13 percent of both polychaete communities, and sessile polychaetes (part of surface-feeding group), which composed 9 percent of the polychaetes in the new pit and 11 percent in the old pit. Whereas motile, infaunal, and surface-feeding polychaetes were nearly equally important in the old pit, motile, surface-feeding polychaetes dominated other functional groups within the new pit.

Table 5

Species Accounting for a Cumulative 50 Percent of the Total Faunal Sample*

Species - New Pit	Percent of Sample	Species - Old Pit	Percent of Sample
Parvilucina multidentata	9.5	*Aricidea philbinae***	13.7
Cupuladria sp.**	8.7	*Cupuladria* sp.**	7.8
*Aricidea philbinae***	7.1	*Rhepoxynius episforma*	5.9
Prionospio fallax	6.3	*Branchiostoma caribaeum*	4.9
*Lucina nassula***	4.8	*Armandia maculata***	3.9
*Armandia maculata***	4.0	*Ophelina* sp.**	3.9
Telidora sp.	4.0	*Lucina nassula*	3.9
Ophelina sp.**	3.2	*Chone* sp. 2	2.9
Terebellidae sp. 1	3.2	*Orbiniidae* sp.	2.9
Total percent	50.8		49.8

* New pit compared to old pit (** indicates species common to both pits).

Table 6

Numerical Comparisons of New and Old Borrow Pits for Final Sampling Period

Parameter	New Pit		Old Pit
Number of species	47		50
Number of individuals/m^2	870		694
H'	5.10		5.11
e	3.05		3.01
CCs		0.31	
PS		0.35	

PART IV: DISCUSSION

57. Environmental disturbance is an important fact of life for shallow-water marine organisms. Storm waves, shifting substrata, longshore currents, temperature variations, and other physical factors, as well as various biological influences (e.g., competition and predation), play an important role in determining the structure and composition of benthic communities. Species living in this environment must either be capable of withstanding these influences or of quickly recolonizing locally perturbed areas from which they have previously been extirpated. For most benthic invertebrates, the latter response is more common.

58. Consequently, most nearshore benthic invertebrates tend to be r-strategists rather than K-strategists, which are more common in deeper, relatively stable areas of the seafloor (Sanders 1979). According to Odum (1969), r-strategists are characteristically small-bodied, short-lived, and have high fecundity, efficient dispersal mechanisms, and rapid growth rates. Species possessing these r-selected characteristics are relatively poor biotic competitors and, in the course of succession, are eventually replaced by more competitive K-selected species. The K-strategists are generally larger in size than r-strategists, long-lived, and have low fecundity, poor dispersal mechanisms, and slow growth rates. Recolonization of a disturbed area is thus generally initiated by r-strategists. Theoretically, r-selected species change the physical environment so that it can later be occupied by the more K-selected species (Connell and Slatyer 1977; Rhoads, Allen, and Goldhaber 1977). In unstable or frequently perturbed habitats, however, r-selected species may continue to predominate.

59. Sediment grain size, chemical composition of sediments, and organic content have been found to influence recruitment (McNulty, Work, and Moore 1962; Thorson 1966; Gray 1974; Mauer and Leathan 1981). McCall (1977), in a study of a disturbed bottom in Long Island Sound, found considerable local differences in community species composition caused by sediment grain size heterogeneity. Conversely, Zajac and Whitlatch (1982), in a disturbance study at Alewife Cove, in southeastern Connecticut, found that sediment characteristics did not strongly influence the end product of recolonization.

60. Rates and patterns of colonization are also affected by a number of biotic factors such as availability of larvae, competition (Rhoads, Allen, and

Goldhaber 1977), life histories (Grassle and Sanders 1973), presence of adults of the same species (Crisp 1969), sediment microbes (Gray 1974), and "trophic group amensalism" (Rhoads and Young 1970).

61. Rates of recolonization demonstrated in the present study were comparable to those reported in previous studies of disturbed soft-bottom habitats (Simon, Doyle, and Conner 1976; Oliver et al. 1977; Conner and Simon 1979; Van Dolah, Calder, and Knott 1984) and in studies using defaunated sediment (McCall 1977; Rhoads, McCall, and Yingsi 1978; Zajac and Whitlatch 1982). These studies showed that recolonization is extremely rapid, and that community characteristics such as faunal abundance, H', e, and species composition, were equivalent to those in the surrounding community within as little as 3 months postdisturbance (Saloman, Naughton, and Taylor 1982).

62. In South Carolina, a study of estuarine dredging and dredged material disposal showed substantial recovery within 3 months and no long-term reduction in faunal abundance or changes in dominant species composition (Van Dolah, Calder, and Knott 1984). Following beach nourishment at Panama City, Fla., Saloman, Naughton, and Taylor (1982) showed faunal recovery, in terms of abundance, within 3 months, and total recovery based on species richness, diversity, equitability, faunal similarity, and stability within 9 months. Results of a study following oyster shell dredging in Tampa Bay showed that recovery, relative to background conditions, occurred within 6 to 12 months (Simon, Doyle, and Conner 1976). In the Tampa Bay study, recovery was based on the number of species, faunal densities, and biomass.

63. Rhoads, McCall, and Yingsi (1978) studied the effects of dredging and dredged material disposal in Long Island Sound. The authors reported recovery at the borrow site within 10 to 12 months with regard to faunal densities and species composition. Though recovery of faunal densities also occurred at the disposal site, species composition was still significantly different from that at a reference station, even after 24 months.

64. Additional studies conducted in estuarine and protected waters have shown recovery periods of less than 1 year (McCall 1977, Oliver et al. 1977).

65. Initial colonization of the new pit resulted from larval recruitment as well as from adult migration, including resettlement of individuals suspended during dredging or immigration through the slumping of pit walls. The latter two mechanisms have recently been shown to be important means of recruitment (Van Dolah, Calder, and Knott 1984). The first sampling period at

Delray Beach was characterized by the immigration of both highly motile, adult peracarid crustaceans and several species of newly metamorphosed polychaetes with opportunistic life histories. Peracarid crustaceans and polychaetes accounted for 89.3 percent of the fauna and 60 percent of the species collected at the first sampling period. These two groups of organisms also have been found to predominate in the early phases of colonization in other disturbed areas (Saila, Pratt, and Polgar 1972; Rosenberg, 1972, 1973; Grassle and Grassle 1974; Dauer and Simon 1976; McCall 1977; Rhoads, McCall, and Yingsi 1978).

66. Molluscs were slow to colonize the new pit. Periodic molluscan settlement was in most cases followed by nearly complete mortality. No adult molluscs were collected during the study, including the bivalve *Parvilucina multidentata*, which was the only molluscan species collected in all six sampling periods. Oliver et al. (1977) reported similar molluscan mortality in a study of dredged material disposed at various depths in Monterey Bay, California. Simon and Dauer (1977) also noted the slow appearance of molluscs in a disturbed area in Tampa Bay. The authors surmised that the phenomenon may be related to their more limited dispersal abilities and reproductive seasonality. Reasons for the poor survivorship of recently settled molluscs off Delray Beach are not clear. Species diversity values reported from our study were generally high. Diversity H' for the initial sampling period, 21 days after dredging, was 4.21 and equitability e was 2.73. The greatest H' values occurred during the last two sampling periods (5.09 and 5.10, respectively). Other benthic studies conducted in the shallow coastal waters off southeastern Florida have shown that high H' values ($H' > 4.00$) are characteristic of the area (Turbeville and Marsh 1982; D. Deis, Florida Department of Environmental Resources, personal communication).

67. The H' values of this magnitude are higher than those shown in most disturbance studies, most of which were conducted in bay and estuarine areas, and thus primarily in very fine-grained (>5 ϕ) sediments. McCall (1977), for example, found species diversity values as low as 0.90 and only as high as 1.40 in Long Island Sound. The estuarine environment is a relatively unstable, high-stress environment typically dominated by a limited number of r-selected species that are adapted to these conditions. Diversity and equitability values are generally low in these areas (Sanders 1968).

68. Reasons for the high diversities of soft-bottom communities in southeastern Florida may include: (a) frequent bottom disturbances by waves and currents (McCall 1977, Oliver et al. 1977) or disturbance by larger bottom-feeding organisms that could lead to a mosaic of successional states (Johnson 1973, Van Blaricom 1978), (b) sediment heterogeneity (Rhoads, Allen, and Goldhaber 1977, Rhoads, McCall, and Yingsi 1978), and (c) settlement of larvae from local and distant high-diversity areas via the Florida current. Low-latitude benthic communities are characteristically more diverse than those occurring in similar habitats in higher latitudes (Sanders 1968).

69. In the present study, the extent of faunal recovery in the new pit was assessed primarily on the basis of community structure (H', e, species richness, faunal similarity, and species composition) relative to that in the old pit. It was felt that the old pit provided a more useful reference than the undisturbed bottom because of the greater similarity of physical conditions, including several important determinants of community structure such as current conditions and sediment characteristics. The mean grain size of sediments in the old pit was smaller (2.25 ϕ) than on the undisturbed bottom (2.10 ϕ) and closer in size to that in the new pit (Table 2). Samples collected in June 1979 from the old and new pits indicated close similarities in several aspects of community structure, including number of species, faunal densities, H', and e (Table 6).

70. Recovery may also be measured in terms of functional group distributions. Rhoads, Allen, and Goldhaber (1977) analyzed colonization of two dredged material disposal sites in Long Island Sound by dividing the recovery sequence into three stages according to changing patterns of abundance and trophic structure. Stage I represented initial recruitment of shallow-burrowing surface-deposit feeders and suspension feeders, Stage II was characterized by new recruitment of deeper feeding infauna, and Stage III showed the establishment of deeper feeding deposit feeders. A combination of several attributes, including organism size, feeding strategy, and motility, was used to separate colonizing groups into early, middle, and late stages of community development in defaunated sediment trays (McCall 1977) and dredged material disposal sites (Rhoads, McCall, and Yingsi 1978) in Long Island Sound. They found that small, sedentary, surface-deposit feeders were early colonizers, followed by intermediate size, motile, surface-deposit and suspension feeders. Large, very motile surface-deposit and suspension feeders characterized the

late stage of colonization. Rhoads, McCall, and Yingsi (1978) found the first two stages to be consistent with Odum's (1969) conceptual model of succession in ecosystems.

71. A comparison of functional group distribution of polychaetes in the old and new pits at Delray Beach demonstrates that the percentages of omnivorous-feeding polychaetes were similar (Figure 9). However, surface feeders were much more prevalent in the new pit (67 percent of the polychaete fauna) than in the old pit (42.5 percent), and infaunal feeders were less common (20 and 42.5 percent, respectively). Comparisons of motility group distributions (Figure 10) between the two pits showed roughly equivalent proportions of discretely motile polychaetes (11 and 8.5 percent in the new and old pits, respectively). The new and old pits were dissimilar, however, with regard to sessile (32 and 8.5 percent) and motile (58 and 83 percent) functional groups.

72. Our results generally agree with those of McCall (1977), Rhoads, Allen, and Goldhaber (1977), and Rhoads, McCall, and Yingsi (1978). Surface-deposit and suspension feeders dominated the early stages of recolonization. Infaunal and subsurface-deposit feeding, although never dominant feeding types, showed an increase with time. Our results also support Odum's (1969) model (modified for marine benthic ecology by Rhoads, Allen, and Goldhaber 1977), which predicted that surface-deposit and suspension feeders would dominate early stages of colonization in marine soft-bottom habitats.

73. In conclusion, based on many of the quantitative community criteria used, recovery within the new pit resulted within a short period of time, certainly within the 1-year study period. However, some qualitative differences remained between the new and old pits, as well as differences in polychaete feeding and motility group distributions. Differences in species composition may have resulted from sediment grain size differences between the new and old pits.

74. Qualitative and quantitative differences between disturbed and undisturbed (or less recently disturbed) areas in the above study may reflect the difficulty in selecting a "control" site for assessing the effects of disturbance in the offshore sandy bottom community. Even slight differences in depth, current patterns, or sediment characteristics may create conditions that are more or less conducive to the settlement of highly selective planktonic larvae. In areas of high species diversity, such as the coastal waters

of southeastern Florida, the resulting differences in community composition could be especially pronounced.

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APPENDIX A: LISTING OF SPECIES COLLECTED IN NEW PIT, BY SAMPLING PERIOD

Note: Species listing shows the number of individuals per sampling period, the total number of individuals per species, the percent of the total number of individuals comprised by each species, and the cumulative percent of the sample for species collected in the new pit.

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total	Percent Total	Cumulative Total
Aricidea philbinae	15	14	45	3	5	9	91	8.16	8.16
Lumbrineris testudinum	1	11	37	24	2	2	77	6.91	15.07
Cupuladria sp.		8	15	15	14	11	63	5.65	20.72
Haploscoloplos foliosus	2	29	26	4	1		62	5.56	26.28
Chone sp. 1	8	3	4	15	21	2	53	4.75	31.03
Prionospio fallax	7	15	3	2	15	8	50	4.48	35.51
Phtisica marina	26	3		1	17		49	4.39	39.90
Parvilucina multidentata	1	10	10	1	6	12	40	3.59	43.49
Ampelisca abdita		2	10	18	6	2	38	3.41	46.90
Paraprionospio pinnata		15	22		1		38	3.41	50.31
Aricidea sp. 1	18	4	6	1	2	1	32	2.87	53.18
Armandia maculata	6	12	2	2	5	5	32	2.87	56.05
Ophelina sp.			2	16	7	4	29	2.60	58.65
Terebellidae sp. 1	20			2	3	4	29	2.60	61.25
Branchiomma sp.	12			8	1		22	1.97	63.22
Rhepoxynius episforma		1	3	4	11		19	1.70	64.92
Cirrophorus furcatus	2	1	7	3		3	16	1.43	66.35
Prionospio dayi		1		2	7	3	16	1.43	67.78
Aoridae sp. 1	6	4	2		1	1	13	1.17	68.95
Cyclapsis varians		3	4	1	4	2	13	1.17	70.12
Hippolytidae sp. (juv.)		2			7	4	13	1.17	71.29
		2							

(Continued)

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total	Percent Total	Cumulative Total
Capitellidae sp. 1	2	3	1	1	3		10	0.90	72.19
Cirrophorus lyriformis	4	3				3	10	0.90	73.09
Branchiostoma caribaeum	1	1	3	1	3		9	0.81	73.90
Codakia orbicularis			9		5		9	0.81	74.71
Corbulidae sp.			4		2		9	0.81	75.52
Fabricia sabella	2			5			9	0.81	76.33
Oligochaeta sp. 2		1	6	2	4		9	0.81	77.14
Tellina versicolor	1	1	2	1	8		9	0.81	77.95
Bivalve sp. 1							8	0.72	77.67
Glycera tesselata		6			1	1	7	0.63	79.30
Lucina nassula					2	6	7	0.63	79.93
Nemertea sp. 4			5				7	0.63	80.56
Sigalion arenicola		2	2	2		1	7	0.63	81.19
Nemertea sp. 3			5	1			6	0.54	81.73
Nemertea sp. 10		1	5				6	0.54	82.27
Sthenelais boa			1	4		1	6	0.54	82.81
Veneridae sp. 2	2	1			1	2	6	0.54	83.35
Veneridae sp. 1		4		1			5	0.45	83.80
Telidora sp.						5	5	0.45	84.25
Ophiuroidea sp. 1 (juv.)				5			5	0.45	84.70
Spio sp.				1		4	5	0.45	85.15
Alpheus floridanus		4					4	0.36	85.51

(Continued)

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total	Percent Total	Cumulative Total
Nemertea sp. 1	1		2	1			4	0.36	85.87
Nereiphylla sp.		1		1	2		4	0.36	86.23
Orbiniidae sp.		4					4	0.36	86.59
Parapeneus longirostris	2	2					4	0.36	86.95
Parthenopinae sp.		1		1	2		4	0.36	87.31
Poecilochaetus johnsoni		2	2				4	0.36	87.67
Processa bermudensis						4	4	0.36	88.03
Terebellidae sp. 2	2	2					4	0.36	88.39
Alpheus sp.		2	1				3	0.27	88.66
Aricidea sp. 2				2	1		3	0.27	88.93
Atys caribaea	2				1		3	0.27	89.20
*Caulerpa mexicana**		1			1	1	3		
Glycera capitata	1		1	1			3	0.27	89.47
*Halophila baillonis**						3	3		
Haploscoloplos fragilis	3						3	0.27	89.74
Lumbrineridae sp.		3					3	0.27	90.01
Megalomma pettiboneae				3			3	0.27	90.28
Nemertea sp. 8					3		3	0.27	90.55
Nemertea sp. 12						3	3	0.27	90.82
Portunidae sp. 1	2	1					3	0.27	91.09
Prionospio cirrobranchiata					3		3	0.27	91.36
Prionospio sp. 1				2	1		3	0.27	91.63
Spiophanes bombyx	2				1		3	0.27	91.90

(Continued)

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total	Percent Total	Cumulative Total
Tellina sp.	1		2		3			0.27	92.17
Alvania sp.					2		2	0.18	92.35
Echinoidea sp. (juv.)						2	2	0.18	92.53
Lumbrineris impatiens						2	2	0.18	92.71
Macoma constricta			1		1		2	0.18	92.89
Megalomma phyllisae		1	1				2	0.18	93.07
Megalomma vesiculosum		1	1				2	0.18	93.25
Mitrella lunata				1	1		2	0.18	93.43
Nemertea sp. 13	1					1	2	0.18	93.61
Nemertea sp. 14			1	1			2	0.18	93.79
Onuphis sp. 2				1	1		2	0.18	93.97
Onuphis sp. 3				1	1		2	0.18	94.15
Prionospio sp. 2					2		2	0.18	94.33
Terebellidae sp. 3		2					2	0.18	94.51
Turbonilla sp.					2		2	0.18	94.69
Anthuridae sp.						1	1	0.09	94.78
Aoridae sp. 2		1					1	0.09	94.87
Asteroides sp. 1 (juv.)				1			1	0.09	94.96
Asteroides sp. 2 (juv.)				1			1	0.09	95.05
Asteroides sp. 3 (juv.)				1			1	0.09	95.14
Automate kingsleyi						1	1	0.09	95.23
Axiothella mucosa		1					1	0.09	95.32

(Continued)

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total	Percent Total	Cumulative Total
Blenniidae sp.		1					1	0.09	95.41
Codakia orbiculata	1						1	0.09	95.50
Campanulidae sp.						1	1	0.09	95.59
Capitellidae sp. 2					1		1	0.09	95.65
Capitellethus sp.						1	1	0.09	95.77
Caulleriella alata			1				1	0.09	95.86
Ceratonereis mirabilis				1			1	0.09	95.95
Chloeia viridis		1					1	0.09	96.04
Cylichna verrillii					1		1	0.09	96.13
Diplodon punctata						1	1	0.09	96.22
Ehlersia sp.				1			1	0.09	96.31
Genetyllis sp.			1				1	0.09	96.40
Glycera robusta			1				1	0.09	96.49
Haplosyllis sp.					1		1	0.09	96.58
Holothuroidea sp.		1					1	0.09	96.67
Opistognathidae sp.	1						1	0.09	96.76
Leptochelia sp.		1					1	0.09	96.85
Lucina sp.						1	1	0.09	96.94
Mellita quinquesperforata (juv.)						1	1	0.09	97.03
Metharpinia floridana					1		1	0.09	97.12
Monoculodes sp.	1						1	0.09	97.21

(Continued)

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total	Percent Total	Cumulative Total
Naticidae sp.						1	1	0.09	97.30
Nereidae sp. 1						1		0.09	97.39
Nereidae sp.			1				1	0.09	97.48
Nemertea sp. 2				1			1	0.09	97.57
Nemertea sp. 5					1		1	0.09	97.66
Nemertea sp. 6					1		1	0.09	97.75
Nemertea sp. 7					1		1	0.09	97.84
Nemertea sp. 9	1						1	0.09	97.93
Nemertea sp. 11						1	1	0.09	98.02
Nemertea sp. 15				1			1	0.09	98.11
Odostomia sp.					1		1	0.09	98.20
Oligochaete sp. 1	1						1	0.09	98.29
Onuphis eremita				1			1	0.09	98.38
Onuphis sp. 1	1						1	0.09	98.47
Paraonidae sp.						1	1	0.09	98.56
Polycirrus carolinensis			1				1	0.09	98.65
Prionospio sp. 3						1	1	0.09	98.74
Pycnogonida sp.						1	1	0.09	98.83
Scalibregmidae sp.		1					1	0.09	98.92
Sipunculid sp. 1			1				1	0.09	99.01
Sipunculid sp. 2				1			1	0.09	99.10
Sthenelais limicola			1				1	0.09	99.19

(Continued)

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total	Percent Total	Cumulative Total
Syllidae sp.				1			1	0.09	99.28
Tellina nitens						1	1	0.09	99.37
Tellina strigella						1	1	0.09	99.46
Tellina squamifera					1		1	0.09	99.55
Terebellidae sp. 4					1		1	0.09	99.64
Typhosyllis sp.				1			1	0.09	99.73
Veneridae sp. 3					1		1	0.09	99.82
Bivalve sp. 2						1	1	0.09	99.91
Bivalve sp. 3			1				1	0.09	100.00

APPENDIX B: LISTING OF SPECIES COLLECTED IN NEW PIT, BY FAUNAL GROUPS

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total
Phylum Annelida							
Class Polychaeta							
Aricidea philbinae	15	14	45	3	5	9	91
Lumbrineris testudinum	1	11	37	24	2	2	77
Haploscoloplos foliosus	2	29	26	4	1		62
Chone sp.	8	3	4	15	21	2	53
Prionospio fallax	7	15	3	2	15	8	50
Paraprionospio pinnata		15	22		1		38
Aricidae sp. 1	18	4	6	1	2	1	32
Armandia maculala	6	12	2	2	5	5	32
Ophelina sp.			2	16	7	4	29
Terebellidae sp. 1	20			2	3	4	29
Branchiomma sp.	12	1		8	1		22
Cirrophorus furcatus	2	1	7	3		3	16
Prionospio dayi		4		2	7	3	16
Capitellidae sp. 1	2	3	1	1	3		10
Cirrophorus lyriformis	4	3				3	10
Fabricia sabella	2			5	2		9
Glycera tesselata		6				1	7
Sigalion arenicola		2	2	2		1	7
Sthenelais boa			1	4		1	6
Spio sp.				1		4	5
Nereiphylla sp.		1		1	2		4
Orbiniidae sp.		4					4
Poecilochoetus johnsoni		2	2				4
Terebellidae sp. 2	2	2		2			4
Aricidea sp. 2				1	1		3
Glycera capitata	1		1				3
Haploscolopolos fragilis	3						3
Lumbrineridae sp.		3					3
Megalomma pettiboneae				3			3
Prionospio cirrobranchiata					3		3

(Continued)

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total
Phylum Annelida							
Class Polychaeta							
Prionospio sp. 1				2	1		3
Spiophanes bombyx	2				1		3
Lumbrineris impatiens						2	2
Megalomma phyllisae			1		1		2
Megalomma vesiculosum		1	1				2
Onuphis sp. 2				1	1		2
Onuphis sp. 3				1	1		2
Prionospio sp. 2					2		2
Terebellidae sp. 3		2					2
Axiothella mucosa		1					1
Capitellidae sp. 2					1		1
Capitellethus sp.						1	1
Caulleriella alata			1				1
Ceratonereis mirabilis				1			1
Chloeia viridis		1					1
Ehlersia sp.				1			1
Genetyllis sp.			1				1
Glycera robusta			1				1
Haplosyllis sp.					1		1
Nereidae sp. 1						1	1
Nereidae sp.			1				1
Onuphis emerita				1			1
Onuphis sp. 1	1						1
Paraonidae sp.						1	1
Polycirrus carolinensis			1				1
Prionospio sp.	1					1	
Scalibregmidae sp.		1					1
Sthenelais limicola			1				1
Syllidae sp.				1			1
Terebellidae sp. 4					1		1
Typhosyllis sp.				1			1

(Continued)

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total
Phylum Annelida							
Class Oligochaete							
Oligochaete sp. 1	1						1
Oligochaete sp. 2		1	6	2			9
Phylum Arthropoda							
Class Crustacea							
Subclass Malacostraca							
Superorder Peracarida							
Order Cumacea							
Cyclapsis varians		2	4	1	4	2	13
Order Tanaidacea							
Leptochelia sp.		1					1
Order Isopoda							
Anthuridae sp.						1	1
Order Amphipoda							
Phtisica marina	26	3		1	17	2	49
Ampelisca abdita		2	10	18	6	2	38
Rhepoxynius episforma		1	3	4	11		19
Aoridae sp. 1	6	3	2		1	1	13
Aoridae sp. 2		1					1
Metharpinia floridana					1		1
Order Copepoda							
Monoculodes sp. 1	1						1

(Continued)

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total
Superorder Eucarida							
Order Decapoda							
Hippolytidae sp. (juv.)		2			7	4	13
Alpheus floridanus		4					4
Parthenopinae sp.		1		1	2		4
Parapenaeus longirostris	2	2					4
Processa bermudensis						4	4
Alpheus sp.		2	1				3
Portunidae sp. 1	2	1					3
Automate kingsleyi						1	1
Subphylum Pycnogonida							
Class Pantopoda							
Pycnogonidae sp.						1	1
Phylum Ectoprocta							
Cupuladria sp.		8	15	15	14	11	63
Phylum Mollusca							
Class Bivalvia							
Parvilucina multidentata	1	10	10	1	6	12	40
Codakia orbicularis	1		9				10
Corbulidae sp.			4		5		9
Tellina versicolor	1	1	2	1	4		9
Bivalve sp. 1					8		8
Lucina nassula					1	6	7
Veneridae sp. 2	2	1			1	2	6
Veneridae sp. 1		4		1			5
Telidora sp.						5	5
Tellina sp.					1	2	3

(Continued)

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total
Phylum Mollusca							
Class Bivalvia (Cont.)							
Macoma constricta			1		1		2
Codakia orbiculata	1						1
Diplodon punctata						1	1
Lucina sp.						1	1
Tellina nitens						1	1
Tellina strigella						1	1
Tellina squamifera					1		1
Veneridae sp. 3					1		1
Bivalve sp. 2						1	1
Bivalve sp. 3			1				1
Class Gastropoda							
Atys caribaea	2				1		3
Alvania sp.					2		2
Mitrella lunata				1	1		2
Turbonilla sp.					2		2
Cylichna vermilli					1		1
Naticidae sp.						1	1
Odostomia sp.					1		1
Phylum Chordata							
Subphylum Cephalochordata							
Branchiostoma caribaeum	1	1	3	1	3		9
Subphylum Vertebrata							
Class Osteichthyes							
Family Blenniidae							
Blenniidae sp.		1					1

(Continued)

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total
Phylum Chordata							
Subphylum Vertebrata							
Class Osteichthyes							
Family Opistognathidae							
Opistognathidae sp.	1						1
Phylum Rhynchocoela							
Nemertea 4			5				7
Nemertea 3			5	1	2		6
Nemertea 10		1	5				6
Nemertea 1	1		2	1			4
Nemertea 8					3		3
Nemertea 12						3	3
Nemertea 13	1					1	2
Nemertea 14			1	1			2
Nemertea 2				1			1
Nemertea 5					1		1
Nemertea 6					1		1
Nemertea 7					1		1
Nemertea 9	1						1
Nemertea 11						1	1
Nemertea 15				1			1
Phylum Echinodermata							
Class Ophiuroidea							
Ophiuroidea sp. 1 (juv.)				5			5
Class Echinoidea							
Echinoidea sp. (juv.)					2		2
Mellita quinquesperforata (juv.)						1	1

(Continued)

Species	21 Days	98 Days	170 Days	246 Days	296 Days	395 Days	Total
Phylum Echinodermata							
Class Asteroidea							
Asteroidea sp. 1 (juv.)				1			1
Asteroidea sp. 2 (juv.)				1			1
Asteroidea sp. 3 (juv.)				1			1
Class Holothuroidea							
Holothuroidea sp.		1					1
Phylum Cnidaria							
Class Hydrozoa							
Campanulidae sp.						1	1
Phylum Sipuncula							
Sipuncula sp. 1			1				1
Sipuncula sp. 2				1			1

APPENDIX C: LISTING OF SPECIES COLLECTED IN OLD PIT

Species	Number	Percent Total	Cumulative Percent
Aricidea philibinae	14	13.72	13.72
Cupuladria sp.	8	7.84	21.56
Rhepoxynius episforma	6	5.88	27.44
Branchiostoma caribaeum	5	4.90	32.34
Armandia maculata	4	3.92	36.26
Lucina nassula	4	3.92	40.18
Ophelina sp.	4	3.92	44.10
Ampelisca abdita	3	2.94	47.04
Atys caribaea	3	2.94	49.98
Chone sp. 2	3	2.94	52.92
Orbiniidae sp. 1	3	2.94	55.86
Anthuridae sp. 2	2	1.96	57.82
Capitellidae sp. 2	2	1.96	59.78
Haploscoloplos foliosus	2	1.96	61.74
Haploscoloplos fragilis	2	1.96	63.70
Lumbrineris testudium	2	1.96	65.66
Nemertea 14	2	1.96	67.62
Apsceudes sp.	1	0.98	68.60
Capitellidae sp. 1	1	0.98	69.58
Capitellidae sp. 3	1	0.98	70.56
Cirrophorus furcatus	1	0.98	71.54
Corbulidae sp.	1	0.98	72.52
Cylichna verrilii	1	0.98	73.50
Divaricella dentata	1	0.98	74.48
c.f. Eusylinae	1	0.98	75.46
Fabrisabella sp.	1	0.98	76.44
Gastropod sp.	1	0.98	77.42
Gammaridae sp.	1	0.98	78.40
Glottidia c.f. *pyramidata*	1	0.98	79.38
Glyceridae sp. 1	1	0.98	80.36
Harpacticoida sp. 1	1	0.98	81.34
Lucina sp.	1	0.98	82.32

(Continued)

Species	Number	Percent Total	Cumulative Percent
Lumbrineris tenuis	1	0.98	83.30
Mayerella articulata	1	0.98	84.28
Nemertea 1	1	0.98	85.26
Nemertea 2	1	0.98	86.24
Parvilucina multidentata	1	0.98	87.22
Pleuroneris tridentata	1	0.98	88.20
Polinices duplicatus	1	0.98	89.18
Polycladida sp.	1	0.98	90.16
Polynoidae sp.	1	0.98	91.14
Prionospio fallax	1	0.98	92.12
Prionospio dayi	1	0.98	93.10
Processa bermudensis	1	0.98	94.08
Synchelidium americanum	1	0.98	95.06
Tellina sp.	1	0.98	96.04
Tellina texana	1	0.98	97.02
Verneridae sp.	1	0.98	98.00
Verneridae sp. 4	1	0.98	98.98
Volvulella persimilis	1	0.98	99.96

APPENDIX D: LISTING OF SPECIES COLLECTED IN OLD PIT, BY FAUNAL GROUPS

Species	Number
Phylum Annelida	
Class Polychaeta	
Aricidea philbinae	14
Armandia maculata	4
Ophelina sp.	4
Chone sp. 2	3
Orbiniidae sp.	3
Capitellidae sp. 2	2
Haploscoloplos foliosus	2
Haploscoloplos fragilis	2
Lumbrineris testudinum	2
Capitellidae sp. 1	1
Capitellidae sp. 3	1
Cirrophorus furcatus	1
c.f. Eusylinae	1
Fabrisabella sp.	1
Glyceridae sp. 1	1
Lumbrineris tenuis	1
Mayerella articulata	1
Prionospio dayi	1
Prionospio fallax	1
Polynoidae sp.	1
Phylum Mollusca	
Class Bivalvia	
Lucina nassula	4
Verneridae sp.	1
Corbulidae sp.	1
Parvilucina multidentata	1
Tellina sp.	1

(Continued)

Species	Number
Phylum Mollusca	
Class Bivalvia	
Tellina texana	1
Divaricella dentata	1
Lucina sp.	1
Verneridae sp. 4	1
Pleuromeris tridentata	1
Class Gastropoda	
Atys caribaea	3
Volvulella persimilis	1
Cylichna verrillii	1
Polinices duplicatus	1
Gastropod sp.	1
Phylum Ectoprocta	
Class Bryozoa	
Cupuladria sp.	8
Phylum Arthropoda	
Class Crustacea	
Order Amphipoda	
Rhepoxynius episforma	6
Ampelisca abdita	3
Gammaridae sp.	1
Synchelidium americanum	1
Order Isopoda	
Anthuridae sp.	2
Order Copepoda	
Harpacticoida sp.	1
Order Tanaidacea	
Apscedes sp.	1

(Continued)

Species	Number
Phylum Arthropoda	
Class Crustacea	
Superorder Eucarida	
Order Decapoda	
Processa bermudensis	1
Phylum Chordata	
Subphylum Cephalochordata	
Branchiostoma caribaeum	5
Phylum Rhynchocoela	
Nemertea 14	2
Nemertea 1	1
Nemertea 2	1
Phylum Platyhelminthes	
Class Turbellaria	
Order Polycladida	
Polycladea sp.	1
Phylum Brachiopoda	
Glottidia c.f. *pyramidata*	1